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ABSTRACT

This chapter overviews trends and shifts in research methods in mathematics and science education. It summarizes shifts in some basic assumptions about the role of research in mathematics and science education, background factors that support the proclivities of the researchers represented in the book, foreground factors that the researchers in the book share, and evidence of the research methods they advocate. (KHR)

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ED 478 311

2 Trends and Shifts in Research Methods

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Anthony E. Kelly
Rutgers, the State University of New Jersey

Richard Lesh
Purdue University

All scientists choose, adapt, and create tools appropriate to their reading of problems and opportunities in their fields. In turn, new or adapted tools can change the questions asked and the answers given, leading to new research cycles. The dialectic between the evolution of tools and the refinement of problems characterizes growth in a field.

We are now at a point where the growing maturity of mathematics and science education research has shifted attention from strict adherence to traditional experimental methods as the best path to scientific insight to renewed interest in the development of alternative methods for research. In the past few number of decades, educational researchers have moved into school systems, classrooms, and workplaces and have found a complex and multifaceted world that they feel is not well described by traditional research techniques. In the past, educational phenomena derived their status by surviving a variety of statistical tests. Today, nascent educational phenomena are accorded primacy, and the onus is on research methods to describe them in rich and systematic ways.

What characterizes the sentiment of this book is the recognition that the legitimacy of educational research questions should not be predetermined by or constrained to the potentialities and capabilities of a particular research methodology. Rather, the needs of learning and teaching, and the descriptive, analytic, and communication needs of the

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community of researchers should help bring forth and test a diversity of research methods. These methods may include those borrowed from other traditions (e.g., anthropology) as well as those emerging from within the practices of mathematics and science education research (e.g., teaching experiments, design experiments, action research). Educational research not only wishes to answer questions such as, "Which instructional approach leads to the greatest growth in learning under controlled conditions?" Research also involves model development and model validation—developing productive ways of thinking about problems and opportunities.

More ambitious curricula and more pluralistic pedagogies directed toward understanding, sense making, and broadly applicable intellectual skill, employing new tools and embodying new content, engaging new connections with the world outside the school and university, new connections among different levels of education—all these conspire to complexify the endeavor to achieve reliable knowledge and to limit the effectiveness of simple measures and strategies. These changes in education also interact complexly in a political environment that is tuned for rapid, egalitarian improvement of practice where the meaning of "improvement" is not only unclear, but is in serious contention. Further, innovation is highly decentralized horizontally across sites and, especially, disjointed vertically across levels. Indeed, perhaps the most important factor, not yet built into plans and expectations of most researchers, is the fundamental fact that virtually every idea appearing in later mathematics has conceptual and developmental roots in the earlier years—which means that our understandings of idea growth at the later levels necessarily must take into account the structure of such ideas and the ways those ideas grew from earlier experience, especially but not exclusively, educational experience. The existing political and economic factors and institutional arrangements pull researchers toward simple, local comparisons of isolated innovations in the face of all the contextual change and complexity just identified.

SHIFTS

Behind this shift in methods, there are also shifts in some basic assumptions about the role of research in mathematics and science education. Table 2.1 summarizes a number of these shifts.

TABLE 2.1

Some Shifts in Emphasis in Educational Research in Mathematics and Science with Sample Chapters

Less Emphasis On	More Emphasis On
researcher remoteness or stances of "objectivity"	researcher engagement, participant-observer roles: Chapters by Ball; Cline & Mandinach; Cobb; Confrey & Lachance; Doerr & Tinto; Feldman & Minstrell; Lesh & Kelly; Moschkovich & Brenner; Simon, Steffe & Thompson; Tobin
researcher as expert; the judge of the effectiveness of knowledge transmission using prescripted measures	researcher as coconstructor of knowledge: a learner-listener who values the perspective of the research subject, who practices self-reflexivity: Chapters by Ball; Cline & Mandinach; Cobb; Confrey & Lachance: Doerr & Tinto; Feldman & Minstrell; Lesh & Kelly: Moschkovich & Brenner; Simon, Steffe & Thompson; Tobin
viewing the learner as a lone, passive learner in a classroom seen as a closed unit	viewing the learner both as an individual and social learner within a classroom conceived of as a complex, self-organizing, self-regulating system that is one level in a larger human-constructed system: Chapters by Cline & Mandinach; Cobb; Lesh & Kelly; Steffe & Thompson
simple cause-and-effect or correlational models	complexity theory; systems thinking; organic and evolutionary models of learning and system change: Chapters by Cline & Mandinach; Lesh & Kelly
looking to statistical tests to determine if factors "exist"	F values and Pearson coefficients replaced by thick, ethnographic descriptions; recognition of the theory-ladenness of observation and method: Chapters by Cline & Mandinach; Cobb; Doerr & Tinto; Feldman & Minstrell; Moschkovich & Brenner; Simon, Steffe & Thompson; Tobin
the general applicability of method	the implications of subjects' constructions of content and subject matter for determining meaning: Chapters by Lesh & Clarke; Stroup & Wilensky
one-time measures of achievement (often summative or pre-post)	iterative cycles of observations of complex behaviors involving feedback; design experiments; engineering approaches: Chapters by Battista & Clements; Cobb; Lesh & Kelly; Steffe & Thompson
multiple-choice or other standardized measures of learning	multisensory/multimedia data sources; simulations; performance assessments: Chapters by Clements & Battista; Cooper; Hall; Mestre; Roschelle; Steffe & Thompson
average scores on standardized tests as learning outcomes	Sophistication of content models; the process of models; conceptual development: Chapters by Mestre; Steffe & Thompson; Lesh, Hoover, Hole, Kelly, & Post

(continued)

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singular dependence on numbers; apparent precision of numbers	awareness of the assumptions of measurement; understanding the limitations of measures; extracting maximum information from measures, and involving interactive, multi-dimensional, dynamic, and graphic displays: Chapters by Lesh, Hoover, Hole, Kelly, & Post; Liebovitch, Todorov, Wood, & Ellenbogen; Stroup & Wilensky; Mestre; Tatsuoka & Boodoo
accepting curricula as given	the historicity of curricula – Dennis; scientific and systematic reassessment of curricula – Battista & Clements; reconceptualization of curricula given technology – Roschelle & Jackiw; reconcepualization of curricula given research – Confrey & Lachance

Over time, field-based educational researchers have come to recognize the sociocultural, historical, systemic, political, cognitive, affective, and physiological aspects of teaching and learning, which motivates them to expand their researchers' armamentarium. Accordingly, the reader will not find in these chapters a silver bullet research methodology. Rather, the authors invite the reader to struggle with them as they propose methods that they feel capture better the saliences in their growing understanding of learning and teaching, while producing an internally consistent, systematic, scientific account of it. Furthermore, the research products are increasingly the result of design studies that involve contributions from teachers, curriculum designers, and students.

RESEARCHERS AS INTERESTED LEARNERS: BACKGROUND FACTORS

Researchers are learners, and their methods reflect their experiences and personalities. The proclivities of the researchers' represented in this book are supported by a number of background factors, many of which apply to all of the authors:

- Pride in their identities as teachers, teacher educators, curriculum developers, software developers, and program developer. In other words, educational researchers are beginning to draw upon more than their narrow training in research methods as a basis for designing and executing studies.
- Direct experiences with the realities of school and workplaces as entities within larger systems.

- A commitment to equity and fairness.
- The growing legitimization of field-based and qualitative methods, particularly ethnographic techniques and participant-observer studies.
- The legitimization of the study of cognition, as exemplified by the emergence and strength of cognitive science. Many early educational researchers began their training during the dominance of behaviorism; from that perspective, learners were organisms to which treatments were applied and whose environments were engineered. With the ascendancy of cognitive psychology, such narrow conceptions of learning have been abandoned.
- The transformative nature of technology, both as a tool in learning and in scientific advances. A number of research projects exemplify this insight, particularly the work in calculus (SIMCALC: http://tango.mth.umassd.edu/simcalc/) and scientific visualization (CoVis: http://www.covis.nwu.edu/). Researchers are using technology to question not only what content is taught, but also to whom it is taught and at what age.
- A commitment to the position (expressed variably) that all learners (researchers included) are active constructors of knowledge. There is a growing rejection of the researcher as the expert—the judge of the effectiveness of knowledge transmission. This view is being replaced by one of self-reflexivity in which the researcher is seen as a learner-listener who respects and models the worlds of others and views him- or herself as a learner (e.g., see chaps. 5, 9, 13, 18 this volume).

RESEARCHERS AS INTERESTED LEARNERS: FOREGROUND FACTORS

In addition to the background factors described in the preceding section, the researchers in this book also share many proactive factors, which evidence themselves in the research methods they advocate. These factors include:

I. A commitment to subject matter. For example, Steffe and Thompson (chap. 11, this volume) are less concerned with how students learn "formal mathematics," but more with how students construct their own understanding of mathematics. Their goal is to *replace* traditional mathematics curricula with curricula informed by insights from the mathematics of students.

Ia. In their chapter, Confrey and Lachance (chap. 10, this volume) explore the teaching of multiplication not as repeated addition, but as involving the operation of splitting. They attempt to meld the functions of research as the disciplined observation of mathematical teaching practice, with research as a transformative process.

Ib. In the analysis by Ball (of her own and Lampert's, Heaton's, and Simon's experiences; chap. 14, this volume), she notes that she and other teacher-researchers have experienced the need to understand mathematics itself more deeply in order to teach it in line with reform efforts, which, in turn, broadens the number and quality of the research questions that can be asked and addressed.

Ic. Mestre (chap. 7, this volume), whose field is physics education, points out that the design of effective assessment task assumes a substantial grounding in subject matter. Moreover, the design of assessment devices (quantitative and qualitative) can effectively limit what a researcher can learn about students' understanding of subject matter knowledge by constraining or overdirecting students' responses to tasks. Mestre argues that the interplay between framing research questions, building and refining assessment tools, the character of evidence, and theory building and refinement is delicate and nonlinear and involved intimately with considerations of subject matter knowledge.

II. A desire to go beyond the identification and documentation of educational phenomena to their reform and improvement (e.g., Confrey, chap. 5, this volume).

III. An openness to employing techniques that provide more bandwidth in the recording, analysis, and dissemination of findings (e.g., chaps. 22, 23, and 24, this volume). In this case we find that researchers are using videotape archives, computer-generated trace files, and Internet-based records to create and support their claims.

IV. A desire to create not only research archives, but also revisable and augmentable, persuasive resources that form the basis for effective action by practitioners (e.g., videotapes of best practice, see Confrey, chap. 5, this volume).

V. An undertaking to increase the sophistication of the various measures used to judge the efficacy of a study. The simplistic uses of number and its apparent precision are disfavored increasingly, as is the thoughtless use of statistics (e.g., Liebovitch, Todorov, Wood & Ellenbogen, chap. 32, this volume). In particular, many authors recognize the immense loss of information that occurs when numbers are used to represent rich phenomena (e.g., Stroup & Wilensky, chap. 31, this volume). In fact, there is a growing effort to develop techniques to extract maximum information from educational measures (e.g., chaps 29 and 31, this volume). There is less singular reliance on "objective" data collection measures (characteristically, multiple-choice paper-and-pencil tests taken by students in isolation from one another) toward the use of multimedia and multisensory data collection approaches (e.g., see chaps 22, 23, and 27, this volume) and toward new approaches to task design such as model-eliciting problems (e.g., Lesh, Hoover, Hole, Kelly & Post, chap. 21, this volume). Greater attention is paid to the models that learners construct, to using the processes of model development as outcomes, and to creating representations of conceptual development compared to descriptions of behavior (e.g. chaps 7, 11, and 21, this volume). In addition, single measures of achievement are being replaced by attention to iterative cycles of observation of complex behaviors

involving feedback (e.g., chaps. 9, 11, 12, 14, 17, and 23, this volume), a commitment to self-reflexivity in all aspects of the research endeavor (e.g., chaps. 9 and 11, this volume), and as exemplified by the entire book, an openness to learn from other traditions of research not only their techniques and methods, but also their approaches to the construction of researchable questions.

RECOGNIZING THE SYSTEMS NATURE AND COMPLEXITY OF EDUCATION

Simple, cause-and-effect models are being replaced by models that take a more systemic, organic, or evolutionary approach to changes in learning and teaching (e.g., chaps. 8, 9, 11, 12, 15, and 17, this volume). The emerging view considers the learner as both an individual and a social learner in a learning environment conceived of as a complex, multilevel, human construction that is self-organizing and self-regulating and that is a part of, and responds to, the needs of larger systems (e.g., chaps. 8, 9, 11, 12, 13, and 30, this volume). There is also a movement away from attempts to draw cause-and-effect implications from data toward greater attention being paid to thick descriptions, narratives, and ethnographic methods, generally. It should be noted that this trend is not without its detractors (see chaps. 19 and 20, this volume).

PROMOTING IMMEDIACY

A number of the authors have seen a need for more immediacy, both in terms of their interaction with their "subjects" and in the connection between research and effective action in practice. There is a shift from a stance of remoteness and researcher "objectivity" to a stance of engagement and immersion. For many of the book's authors, the delay between the findings of "basic research" in psychology (often conducted in laboratory settings) and their effective application in the classroom became too long or was unsatisfactory otherwise. Both factors have led to the development of research-teacher and teacher-researcher models. Examples of efforts to bridge the research-practice divide include varieties of action research (see Feldman &

Minstrell, chap. 16, this volume); varieties of teaching experiments (e.g., Steffe & Thompson, chap. 11, this volume), and transformative teaching experiments (Confrey & LaChance, chap. 10, this volume). This trend can be seen too in chapters 11–15, 17, and 18, this volume.

CHALLENGING THE CURRICULUM AS GIVEN

Many of the book's authors question the curricula as given. Dennis (chap. 28, this volume), for example, points out the historicity of some aspects of mathematics curricula. Roschelle and Jackiw (chap. 27, this volume) call for a reconceptualization of curricula, given advances in technology. Confrey and Lachance (chap. 10, this volume) and Steffe and Thompson (chap. 11, this volume) call for a reconceptualization of curricula, given the findings from research into learning. Finally, Battista and Clements (chap. 25, this volume) call for a scientifically informed systematic reexamination of curricula.

CAVEATS

As we have emphasized in other chapters in this book, it is not the goal of this book to establish a new set of standard techniques. The research designs that are described herein refer to works in progress. Many cautions may be applied to these efforts, some of which are noted here. As Stroup and Wilensky (chap. 31, this volume) point out, "radical individualism"—that is, the tendency to oversell data on individual cases, regardless of how rich the descriptions might be—must be avoided. Both Stroup and Wilensky and Tatsuoka and Boodoo (chap. 29, this volume) are working on statistical solutions to this problem. Lesh, Hoover, et al. (chap. 21, this volume) are addressing the problem by making a mathematical model and its development the focus of attention rather than individual differences, per se. A related concern is avoiding "radical localization," that is, overimmersion in one school or district in which the (re)engineering of its solutions is not mined for lessons that have broader application.

There is also the need to avoid relativism, to avoid sophomoric arguments claiming that, because there are many perspectives, there can be no agreement on robust phenomena. Chapter 19, by Goldin (see also Clement, chap. 20, this volume), explores some of this territory,

particularly the political risks of downplaying concerns of replication and generalization, and defaulting to "storytelling." As Goldin points out, educational researchers must remain aware of the risk of losing political battles through the lack of "hard data." More generally, it is important not to lose sight of content concerns in mathematics and science and the real needs of students and teachers by engaging in esoteric, epistemological, sociological, and anthropological debates.

The final caution is to realize the increased demands on what is a very small community in educational research (see Confrey, chap. 5, this volume). To function as a competent educational researcher, it is now necessary to have increased sophistication in content knowledge in mathematics or science, in new technologies, and in psychology, sociology, ethnography, and methodology. Those who are training the next generation of researchers must pay close attention to this "capacity problem."

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